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METHOD OF MANUFACTURING LIGHTWEIGHT HIGH-STRENGTH MEMBER

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SPECIFICATION

TITLE OF THE INVENTION

METHOD OF MANUFACTURING LIGHTWEIGHT HIGH-STRENGTH MEMBER

TECHNICAL FIELD OF THE INVENTION

The present invention relates to a method of manufacturing a lightweight high-strength member using an aluminum material, and in particular, to a technology effectively applied to the manufacturing of suspension parts for an automobile such as a suspension link or the like.

BACKGROUND OF THE INVENTION

If an aluminum alloy, instead of steel, can be used for the material of a suspension link for an automobile, the weight of the suspension link can be reduced, so a research on the application of the aluminum alloy material also to a part necessary for high strength such as the suspension link has been conducted. Even if the aluminum alloy is used for the suspension link, mechanical properties such as tensile strength, yield strength, and elongation need to satisfy desired values.

When the suspension link is manufactured by using the aluminum alloy as a raw material, in general, first, molten metal is poured into a mold to cast a casting, that is, a preform and then the preform is forged by the use of a forging die to a final formed product, that is, a forging, and then the forging is subjected to a heat treatment. In the

conventional technology, the casting process is carried out by a gravity casting in which the molten metal is poured into the mold by self-weight.

When the aluminum material is cast by the gravity casting, it is important to improve the fluidity of the molten metal in the mold, that is, the castability of the molten metal and to prevent the occurrence of the casting defects such as casting cracks. It is well known that Si is added to the aluminum alloy to improve the castability of the aluminum material, but the excessive addition of Si to the aluminum alloy reduces tensile properties such as elongation and hence can not produce a forging product having excellent mechanical properties.

For this reason, in order to ensure castability and to improve tensile properties, a technology for fining eutectic Si has been proposed, for example, as shown in Japanese Patent Application Laid-Open Publication No. 5-9637 (Related Art 1) and Japanese Patent Application Laid-Open No. 7-109536 (Related Art 2). In this case, in order to fine the eutectic Si as compared with the conventional aluminum alloy such as AC4C and AC4CH and the like, a preform is cast by the gravity casting by the use of the molten metal having a reduced Si content of 2.0 to 3.0 % by weight and then is forged. In this technology, in order to fine the average grain size of the eutectic Si to not more than 20 μm, a P content and a Fe content are regulated or elements such as Na, Sr, Sb are added.

On the other hand, Japanese Patent Application Laid-

Open No. 8-3675 (Related Art 3) discloses an aluminum alloy for forging having a Si content of 0.6 % to 3.0 % by weight in which in order to prevent hot cracks when it is forged, alloy components are adjusted so that the amount of Mg_2Si converted from alloy design values is not less than 1. 5 % by weight and a casting is slowly cooled at a reduced cooling rate. Further, Japanese Patent Application Laid-Open No. 9-3581 (Related Art 4) discloses a technology for making a primary crystal dendrite structure into a block-shaped structure by magnetically or mechanically stirring the molten metal of an aluminum alloy material containing, by weight, 6.5 % to 8.0 % Si when it is cast.

SUMMARY OF THE INVENTION

In the conventional lightweight high-strength member in which the preform formed by casting is forged into the final formed product, the casting is carried out by the gravity casting in which the molten metal is poured into the mold by the self-weight and, in the Related Art 1 and the Related Art 2, the Si content is reduced to reduce the amount of eutectic Si and the eutectic Si is fined, but when the Si content is reduced, casting cracks are produced. So, for the purpose of preventing the occurrence of casting cracks, in the Related Art 3, in order to increase the amount of Mg_2Si content and the amount of Si, the casting cooling rate is reduced. This increases the spacing between branches of the dendrite and arouses the fear of incapability of ensuring the yield

strength.

On the other hand, in order to improve the productivity of the high-strength member, a pressure casting is superior to the gravity casting. However, the pressure casting coagulates the eutectic Si further to form a larger block than the gravity casting, thereby causing a reduction in mechanical properties. For this reason, the gravity casting has been conventionally employed.

In view of these circumstances, the present inventors have conducted various kinds of experiments and researches to manufacture the lightweight high-strength member having a desired tensile strength, yield strength and elongation such as the suspension link and the like by casting and forging the aluminum alloy.

As a result, the inventors found the following fact that while a lot of effort has been conventionally put into the reduction of the Si content when producing the preform, if the Si content is increased to 4.0 % to 10.5 % by weight and Cu is added 0.3 % to 1.3 % by weight, even if the preform is formed by the pressure casting, it is possible to fine the crystalline grain without increasing the size of aggregation of the eutectic Si and thus to produce the final formed product having desired mechanical properties necessary for the suspension parts for the automobile.

An object of the present invention is to manufacture a lightweight high-strength member for an automobile having desired mechanical properties such as a suspension part or the

like.

Another object of the present invention is to manufacture a lightweight high-strength member which can be made by effectively casting the molten metal of the aluminum alloy without producing casting cracks and has desired mechanical properties.

A method of manufacturing a lightweight high-strength member in accordance with the present invention is a method of manufacturing a lightweight high-strength member such as a suspension part for an automobile and is characterized by the steps of: pouring the molten metal of an aluminum alloy containing, by weight, 4.0 % to 10.5 % Si and 0.3 % to 1.3 % Cu into a mold to cast a preform; and hot-forging the preform by the use of a forging die to form a final formed product.

A method of manufacturing a lightweight high-strength member in accordance with the present invention is characterized in that the molten metal is pressure-cast under a pressure of not less than 39 MPa.

A method of manufacturing a lightweight high-strength member in accordance with the present invention is characterized by the further steps of subjecting the part after forging to a solution treatment at a temperature of 530 to 545 °C for 4 to 10 hours, a hardening treatment, and an ageing treatment at a temperature of 170 to 180 °C for 6 to 10 hours.

According to the present invention, a preform is formed by casting the molten metal of an aluminum alloy containing,

by weight, 4.0 % to 10.5 % Si and 0.3 % to 1.3 % Cu, and then is forged by the use a forging die to form a final formed product. As to the casting process, the molten metal can be pressure-cast under a pressure of not less than 39 MPa. This can manufacture a lightweight high-strength member in which eutectic Si is sufficiently dispersed to provide a desired elongation.

It is considered that this is because when the pressure-cast aluminum alloy is cooled and solidified under pressure, an α structure, that is, dendrite is formed but in the case where the Si content of the aluminum alloy is less than 4.0 % by weight, the spaces between branches of the dendrite, that is, arm spacing become narrow and hence Si does not remain in the spaces between the branches but is discharged to the outside between the branches of the dendrite. The discharged Si forms a eutectic structure with aluminum and aggregates each other to form larger blocks outside the dendrite structure. The eutectic Si hardly has toughness and hence reduces the values of tensile strength, yield strength, and elongation.

In contrast, it was found that when the Si content of the aluminum alloy was increased to 4.0 % or more by weight, the spaces between the branches of the dendrite were increased and hence the eutectic Si, which was generated during a solidification process under pressure and was composed of Si and Al, was trapped between the increased space between the branches of the dendrite, whereby the eutectic Si was

dispersed in the whole cast structure and the amount of aggregating eutectic Si was reduced. When the eutectic Si was dispersed to reduce the amount of aggregation, not only tensile strength and yield strength but also elongation could be increased. In particular, when the molten metal of the aluminum alloy containing, by weight, less than 4.0 % was pressure-cast, the eutectic Si was observed to aggregate, but when the molten metal of the aluminum alloy containing, by weight, not less than 4.0 % was pressure-cast, the eutectic Si was observed to be dispersed to less aggregate each other.

On the other hand, it was found that when the aluminum alloy contained, by weight, not less than 10. 5 % Si, the elongation decreased. It is considered that this is because the density of generation of the dendrite decreases and the eutectic structure increases. Therefore, the use of the aluminum alloy containing, by weight, 4.0 % to 10.5 % Si can produce a lightweight high-strength member having desired mechanical properties.

The pressure casting was carried out under conditions of a pouring pressure of not less than 39 MPa, for example, about 98 MPa and a pouring speed of not less than 30 cm/sec, for example. Forming the preform by the pressure casting can increase a cooling rate, fine the cast structure, and hence provide a high yield strength. To be more specific, the spaces between the branches of the dendrite can be fined under about 30 μm and the eutectic Si is trapped in the spaces. However, if the cooling rate can be increased, the same effect

can be obtained also by the gravity casting. In addition to the trapping of the eutectic Si between the branches, by adding Sr, Sb, Ti or B to the material, it is possible to fine the eutectic Si and hence to increase elongation.

In particular, when the aluminum alloy contains, by weight, 0.3 % to 1.3 % Cu, even if the Si content is 4.0 % to 10.5 % by weight, it is possible to prevent the eutectic Si from aggregating when it is cast and hence to improve mechanical properties such as elongation and the like. On the other hand, by adding, by weight, 0.3 % to 1.3 % Mg in addition to Cu, it is possible to increase yield strength.

The preform after casting is formed into the shape of a final formed product by the hot forging. When the preform after casting is forged, it is heated to a temperature of 350 to 450 °C and then is hot-forged, which increases elongation to a value of not less than 10 %. This elongation is a sufficient value as the suspension part for the automobile. The elongation of the preform before forging varies in a range of 7 % to 15 % and the forging can reduce variations in the elongation. It is thought that this is because the cast structure has a little unevenness in segregation and dispersion and because the unevenness in segregation and dispersion can be relieved and the segregation and the dispersion can be rendered harmless by the hot forging to improve the elongation to reduce variations in the elongation.

According to the data of the tension test, there is no difference in tensile strength and yield strength between the

casting and the forging and hence desired yield strength needs to be ensured in the forging process. It is important that when the material having the composition described above is cast, the eutectic Si is trapped in the spaces between the branches of the dendrite and further the eutectic Si is made fine. As described above, since there is no difference in the yield strength between the casting and the forging, in the case where low elongation is not significant, the casting can be used as a final formed product without forging.

The forging is subjected to a T6 heat treatment. This heat treatment has a solution step of heating the forging at a temperature of 530 to 545 °C for 4 to 10 hours, a water hardening step of water-cooling the forging after heating, and an ageing step of heating the forging after water cooling at a temperature of 170 to 180 °C for 6 to 10 hours. In the solution step, alloy components such as Mg, Cu, Si are trapped in the α structure to increase the amount of solid solution and, in the hardening step, the increased solid solution is fixed in the α structure.

When the temperature of the solution treatment is increased, the alloy components in the eutectic portion are dissolved, that is, burned to reduce product properties. In contrast, according to the present invention, since the Si content is in the range 4.0 to 10.5 %, as described above, the eutectic Si is trapped and dispersed between the branches of the dendrite to reduce the amount of aggregation of the eutectic Si to make the solution temperature higher than ever,

which can improve the product properties.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a process flow diagram to show a process for manufacturing a lightweight high-strength member;

FIG. 2 is a cross-sectional view to show a high-pressure casting apparatus of a laterally fastening/ vertically casting type used in a casting process;

FIGS. 3A-1, 3B-1, and 3C-1 show mechanical properties of preforms cast formed by casting three kinds of materials having compositions of A, B, C, namely, 3A-1 shows the mechanical properties of the preform formed by the pressure-casting the material having the composition A, FIG. 3B-1 shows the mechanical properties of the preform formed by pressure-casting the material having the composition B, and FIG. 3C-1 shows the mechanical properties of the preform formed by pressure-casting the material having the composition C;

FIGS. 3A-2, 3B-2, and 3C-2 show mechanical properties of final formed products made by hot-forging the respective performs, namely, FIG. 3A-2 shows the mechanical properties of the final formed product formed by hot-forging the perform, FIG. 3B-2 shows the mechanical properties of the final formed product formed by hot-forging the preform and FIG. 3C-2 shows the mechanical properties of the final formed product formed by hot-forging the preform;

FIG. 4A is the photograph of the micro structures of the preform having compositions of A, FIG. 4B is the

photograph of the micro structures of the preform having compositions of B, and FIG 4C is the photograph of the micro structures of the preform having compositions of C, in which the state where eutectic Si is trapped is shown respectively;

FIGS. 5A is the high-speed X-ray image processing photograph of the preform having compositions of A, FIG. 5B is the high-speed X-ray image processing photograph of the preform having compositions of B, and FIG. 5C is the high-speed X-ray image processing photograph of the preform having compositions of C, in which the state where eutectic segregates like a block is shown respectively;

FIG. 6 is a photograph to show the macro-etching of the preform having a composition of A;

FIG. 7 is a photograph to show the macro etching of the preform having a composition of C; and

FIG. 8 is the photograph of the micro structure of a preform formed by casting a material containing, by weight, 11.1 % Si.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 is a process flow diagram to show a process for manufacturing a suspension link, which is one example of lightweight high-strength members. An aluminum material having the above-mentioned composition is made into a melting state in a melting furnace or the like. The molten metal heated to a temperature of 730 °C is poured into a mold in a casting process under a pouring pressure of 98 MPa to form a

preform of a casting. Thereby, the preform that is the casting part is formed. The casting is preheated to a temperature of 350 °C and then is hot-forged with a forging die to form a final formed product.

The forging part is stripped of burrs, which have been formed during the forging process and called a land portion, in a trimming process and then is sent to a fluorescent defect inspection process where a product test is carried out. An acceptable product is then subjected to a heat treatment to make a final formed product and further is subjected to a necessary machining.

FIG. 2 is a view to show a high-pressure casting apparatus 10 of a laterally fastening/vertically casting type used in the casting process. This casting apparatus has the first and second metallic molds 11, 12, each of which has a depressed portion 13 corresponding to the shape of a casting. One mold 12 is freely moved near to and away from the other mold 11 in the horizontal direction. When both the molds 11, 12 are fastened to each other, the respective recessed portions 13 form a cavity corresponding to the casting.

A molten metal pouring unit 15, which can be freely swung around a supporting shaft 14, is provided below both the molds 11, 12. The molten metal pouring unit 15 has a plunger 17 freely reciprocating in an injection sleeve 16 and the plunger 17 is driven by a pressure cylinder 18. When a preform is cast by the use of the high pressure casting apparatus 10, molten metal is supplied into the injection

sleeve 16 and then the one mold 12 is moved near to the other mold 11 and at the same time the molten metal pouring unit 15 is swung so that the injection sleeve 16 is linear with respect to the mating surface of the mold. Further, the injection sleeve 16 is moved nearer to both the molds 11, 12 and is put into close contact with both the molds 11, 12 and then the pressure cylinder 18 is driven to pour the molten metal into the cavity of the molds 11, 12 at a pouring speed of 30 cm/sec.

(EMBODIMENT)

FIG. 3 shows mechanical properties of the preferred embodiment using three kinds of compositions A, B, and C. FIG. 3A-1 shows the mechanical properties of the preform formed by the pressure-casting the material having the composition A and FIG. 3A-2 shows the mechanical properties of the final formed product formed by hot-forging the preform. Similarly, FIG. 3B-1 shows the mechanical properties of the preform formed by pressure-casting the material having the composition B and FIG. 3B-2 shows the mechanical properties of the final formed product formed by hot-forging the preform. Further, FIG. 3C-1 shows the mechanical properties of the preform formed by pressure-casting the material having the composition C and FIG. 3C-2 shows the mechanical properties of the final formed product formed by hot-forging the preform. Here, when actually manufacturing a product, the final formed product is formed by hot-forging the preform and then is subjected to a T6 treatment. However, in order to compare the mechanical

properties of the preform with those of the final formed product, the preform and the final formed product were subjected to the T6 treatment, respectively. The compositions A, B, and C are as follows.

The composition A contains, by weight, 3.50 % Si, 0.39 % Mg, 0.66 % Cu, and 0.09 % Fe. The composition B contains, by weight, 5.00 % Si, 0.39 % Mg, 0.80 % Cu, and 0.10 % Fe. The composition C contains, by weight, 7.20 % Si, 0.42 % Mg, 0.87 % Cu, and 0.12 % Fe.

It was found that the tensile strength and the 0.2 % yield strength increased for both of the preform after casting and the final formed product as the Si content increased. There was not a large difference in these properties between the preform and the final formed product. However, the final formed product after forging containing 7 % Si had a high tensile strength of 373 MPa and a 0.2 % yield strength of 255 MPa. It was found that variations in these properties tended to be stabilized by the forging as compared with the preform after casting.

It was found that also elongation increased for the preform after casting and the final formed product as the Si content increased and that when comparing the elongation after casting with the elongation after forging, the elongation was increased 5 % by forging for the respective Si contents. In particular, when the Si content is 7 %, the elongation after forging was increased to a high value of 15 % or more. It was found that also variations in elongation was improved clearly

by increasing the Si content and that the variations in the elongation were reduced both for the preform after casting and the product after forging in the 7 % Si.

In contrast, when the Si content was 3 % by weight, as shown in FIG. 3A-2, the variations in elongation became large and was not desirable as a mass-produced product and when the Si content was not more than 4 % by weight, the variations in elongation became large. On the other hand, when the Si content increased to not less than 10.5 % by weight, the density of dendrite decreased and the area occupied by the eutectic Si increased, so that even if Cu is added by weight per cent described above, the elongation of not less than 10 % can not be expected.

As described above, it was found that when the molten metal of the aluminum alloy containing, by weight, 4 % to 10.5 % Si and 0.3 % to 1. 3 % Cu was cast by the pressure casting while it was being rapidly cooled to form the preform and then the preform was forged using the forging die to form the final formed product, a high-strength member having excellent mechanical properties could be produced.

FIGS. 4A to 4C are microscope photographs to show the micro structure of the preforms having the compositions A to C described above and show the state where the eutectic Si is trapped. As shown in FIG. 4A, when the Si content is 3 % by weight, the spaces between branches of the dendrite are narrow and the eutectic Si is discharged outside and is not trapped between the branches. In contrast, as shown in FIGS. 4B and

4C, it is clear that when the Si content increases to 5 % by weight and 7 % by weight, the eutectic Si is trapped between the branches.

FIGS. 5A to 5C are the high-speed X-ray image analysis photographs of the preforms having the compositions A to C and show the state where eutectic was not trapped but segregated like a block.

As shown in FIG. 5A, it can be seen that the eutectic Si aggregates like a block in the center in the preform A having the Si content of 3 % by weight. In the preform B having the Si content of 5 % by weight, as shown in FIG. 5B, the eutectic Si is observed to slightly aggregate. Further, in the preform C having the Si content of 7 % by weight, as shown in FIG. 5C, it is clear that the eutectic Si is fined to the level not to be observed by the X rays.

FIG. 6 is a photograph to show the macro etching of the preform A having the Si content of 3 % by weight and FIG. 7 is a photograph to show the macro etching of the preform C having the Si content of 7 % by weight. As shown in FIG. 6, in the preform A having the Si content of 3 % by weight, segregation aggregating in a large size like a block is observed. In the preform C having the Si content of 7 % by weight, however, it is observed that the segregation does not aggregate in a large size but is dispersed to the level not to be observed.

FIG. 8 is a structure photograph to show a preform formed by pressure-casting a material containing, by weight, 11.1 % Si, 2.4 % Cu, 0.25 % Mg and 0.79 % Fe. In FIG. 8,

white circular island-shaped portions show the α structure of Al and gray fine portions between them show the eutectic structure of Al-Si. As can be seen from FIG. 8, when the material containing, by weight, 11.1 % Si is cast to form the preform, the preform has a structure almost exclusively of eutectic in which the eutectic occupies larger area than the α structure, and even if the preform is forged, it is only expected that the preform will have an elongation of, at most, 2 % to 3 %.

From this result, when an aluminum alloy containing, by weight, 4.0 % to 10.5 % Si and 0.3 % to 1.3 % Cu was pressure-cast and cooled at high cooling rate, most of Al-Si eutectic segregation was trapped by a segregation pool function between the branches of the dendrite to reduce the ratio of aggregation, and to disperse the aggregation. This could produce the lightweight high-strength member having an excellent property of elongation.

On the contrary, in the aluminum alloy having a Si content of not more than 4 %, which originally had little eutectic segregation, because a function of trapping segregation was weak between the branches of the dendrite, almost all generated segregation aggregated at a part, as shown in FIG. 6. As a result, as shown in FIG. 5A, a block-shaped segregation flow pattern was formed. On the other hand, in the case of the aluminum alloy containing, by weight, not less than 10.5 % Si, the density of generation of dendrite was reduced to increase the amount of the eutectic Si. As a

result, this could not produce the lightweight high-strength member having desired elongation.

Needless to say, the present invention is not limited to the above-mentioned preferred embodiment, but can be variously modified within the spirit and scope of the appended claims.

In a method of manufacturing a lightweight high-strength member, having a casting process and a forging process, if a preform is formed by casting an aluminum alloy containing, by weight, 4.0 % to 10. 5 % Si and 0.3 % to 1. 3 % Cu and then the preform is forged to form a final formed product, it is possible to efficiently manufacture a product having desired mechanical properties as suspension parts of an automobile such as a suspension link and the like. Here, by setting the Si content and the Cu content of the aluminum alloy at the values described above, it is possible to fine crystalline grains and to uniformly disperse them without the aggregation of eutectic Si when the aluminum alloy is cast, and thus to manufacture a part having mechanical properties necessary for the suspension parts of the automobile.